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# RADIOSCIENCE LABORATORY

**STANFORD ELECTRONICS LABORATORIES**  
DEPARTMENT OF ELECTRICAL ENGINEERING  
STANFORD UNIVERSITY · STANFORD, CA 94305



THE INVESTIGATION OF MAN-MADE  
MODIFICATIONS OF THE IONOSPHERE

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by

P. A. BERNHARDT, A. V. da ROSA  
and K. M. PRICE

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January 18, 1980

Radioscience Laboratory  
Stanford Electronics Laboratories  
Stanford University  
Stanford, California 94305

## SUMMARY

During the reporting period we have:

- Applied our ionosphere modifications models to the simulation of the results we obtained in the "Lagopedo" experiments in which rocket-borne explosives were detonated in the ionosphere. Although our theory was in general agreement with the observations, the few discrepancies observed permitted the introduction of improvements in our models.
- Solved the problem of hypersonic vapor releases from orbiting vehicles.
- Measured the electron content reduction resulting from the firing of a Centaur rocket in the ionosphere.
- Completed the preliminary design of a new ionosphere diagnostic tool: the Critical Frequency Tracker (CFT).

Description of the Critical Frequency Tracker can be found in our proposal RL 2-80 which should be considered part of this progress report.

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## Chapter 1

### ACCOMPLISHMENTS

The interest in chemical modification of the ionosphere has increased during the past few years owing, not only to the scientific data that such modifications yield, but also to some practical aspect of the problem. In the early days of short wave communications, the ionosphere was the mirror that constrained the electromagnetic waves to propagate along the earth's surface. The bottomside of the ionosphere was of major importance and ground-based ionosondes were tools of great practical value.

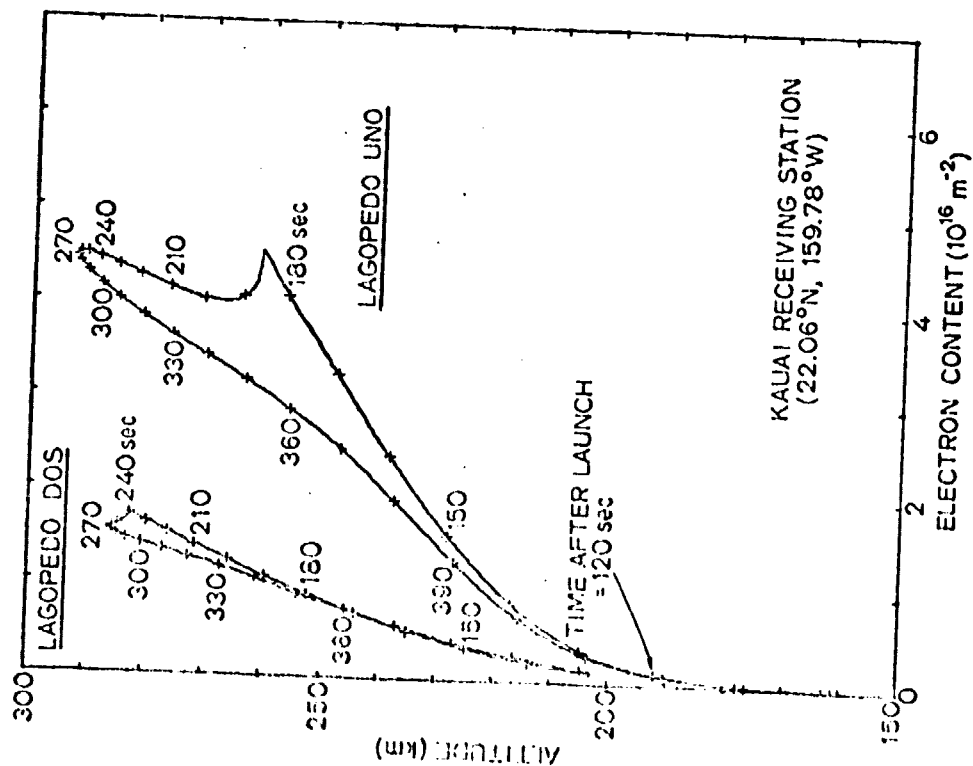
With the advent of satellite relays, the ionosphere became a medium through which the signals had to propagate. To a first order, this ionized region could be ignored by the communications engineer.

Now, with the steady increase of space activities, the ionosphere is a region through which spaceships have to move. If programs such as the Satellite Power System are implemented, the trans-ionospheric traffic will be expanded to a point where many tons of rocket exhaust will be dumped daily into the region. It is, therefore, natural to inquire what effect such traffic will have on the ionospheric environment.

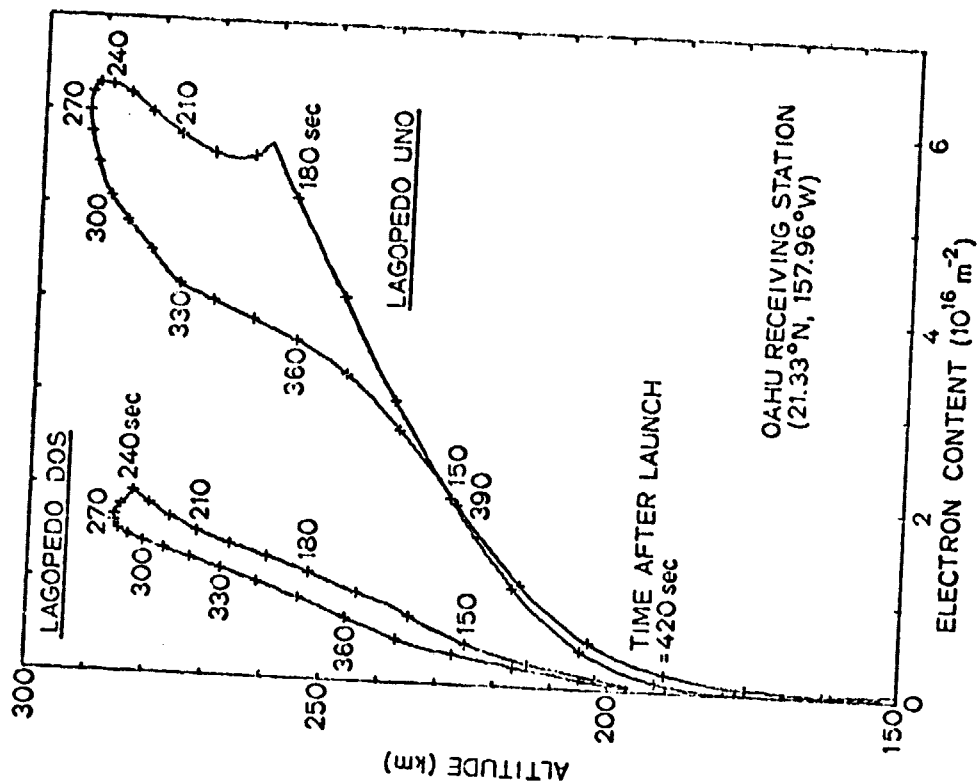
#### 1.1 LAGOPEDO RESULTS

For a number of years, our group at Stanford has been developing theoretical tools to analyse the problem. Experimental confirmation of our predictions were partially obtained from the "Lagopedo" tests. Two rockets launches were made in Hawaii on the 2nd and the 12th of September, 1977, each carrying 88 Kg of explosives which, when detonated in the ionosphere, released  $H_2O$ ,  $CO_2$ , and  $N_2$ . We observed changes in the electron content caused by these foreign gases and described the preliminary results in our previous report.

In the present reporting period, we used the upper atmosphere model of Anderson and Bernhardt (1978) to permit the simulation of the measurements made during the September 2, 1977, Lagopedo ionospheric depletion experiment. The model solves the coupled equations for multi-ion and electron flow along magnetic field lines joining the two hemispheres. The plasma in the ionosphere is chemically coupled to an injected neutral vapor cloud.

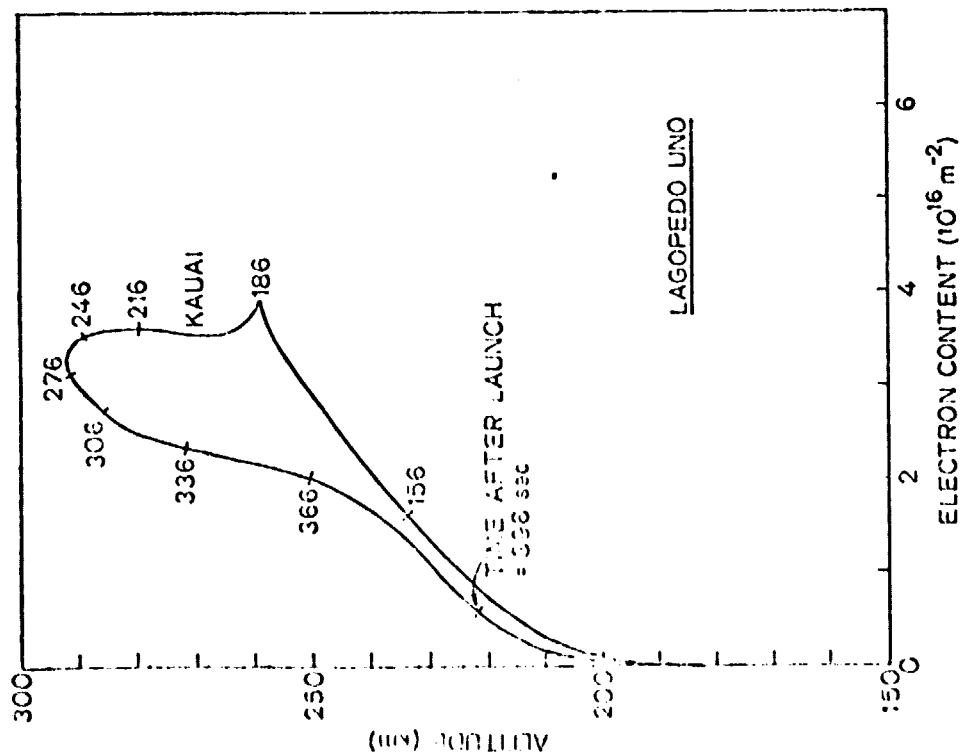


(a) Kauai ground station and

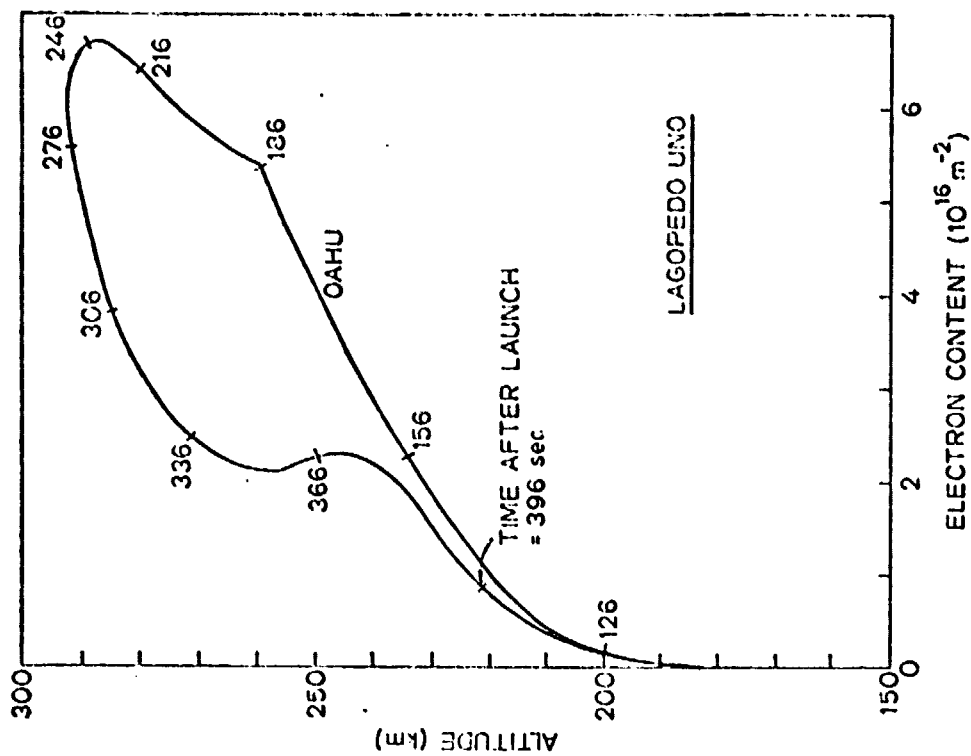


(b) Oahu ground station.

FIGURE 1: Lagopedo Electron Content Measurements taken at



(a) Kauai



(b) Oahu.

FIGURE 2: Simulated Data for the Lagopedo launch as calculated for



Figure 1(a) illustrates the behavior of the electron content as measured between our differential doppler ground station at Kauai and the rocket. Figure 1(b) shows the results obtained at our Oahu ground station. As the rocket rose, the electron content increased rapidly because the region of ionization included in the ray path increased. At about 187 seconds after launch, the 88 kg charge detonated. The resulting gases enhanced the ion recombination and, consequently depressed the electron concentration in an expanding volume of plasma surrounding the point of explosion. The electron content initially decreased notwithstanding the rise of the rocket. Maximum altitude was attained 270 seconds after launch. On its way down, the beacon signals transversed regions of the ionosphere in which the electron concentration was substantially depressed. For this reason, the electron content between ground and beacon was lower than during the ascending part of the trajectory. After 380 seconds into the flight, the rocket had returned to an undisturbed region of the ionosphere and the descending trace coincided with the ascending one, especially as seen from Oahu.

In Figure 2 we present the simulated data as seen from Kauai and Oahu. The general shape of the curves resembles those of Figure 1. However, the calculated electron contents tend to show a larger ionization reduction after the release. The main reason for this discrepancy is that, in the simulated data, we did not take into account the fact that some of the released water vapor condenses and thus is effectively removed from the reaction.

We computed the individual ionic concentrations as a function of time as seen by the rocket flying through the disturbed region. The results of this computation are displayed in Figure 3. Our results have been compared with the measurements made with a rocket-borne ion mass spectrometer (Sjolander et al., 1977). There is good agreement between our calculations and the measurements except with respect to the  $H_3O^+$  concentration. The disagreement is traceable to the recombination rate between electrons and  $H_3O^+$  that we assumed.

The comparison mentioned above increases the confidence in our models for predicting the effects of ionospheric depletion experiments. Improvements, such as considering also the condensation of the released vapors and the updating of reaction rates, are suggested by the comparisons between our models and the actual measurements.

We have not yet simulated Lagopedo II. We have, however, contributed to work carried out in conjunction with the NRL on the analysis of the Lagopedo II ion measurements (Johnson et al., 1980): the electron content measurements made by us were used in the calibration of the Bennet ion mass spectrometer aboard the rocket.

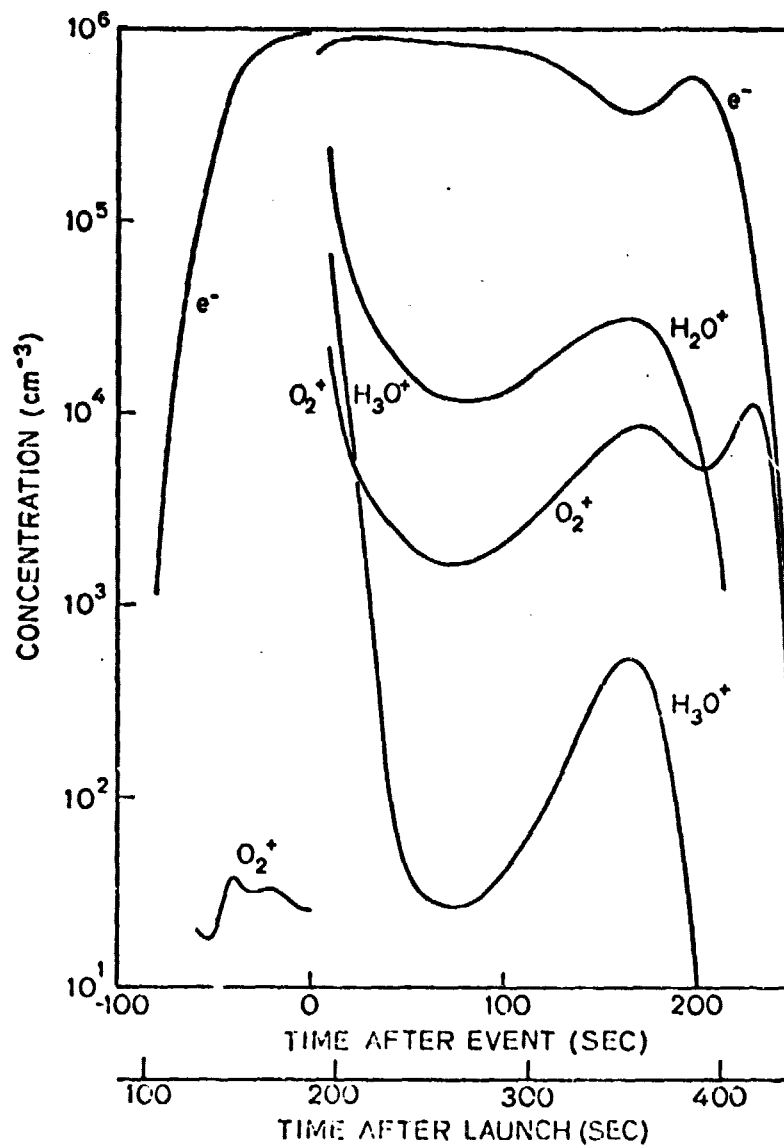


Figure 3: Ionic Concentrations vs. Time

## 1.2 INJECTION OF NEUTRALS AT ORBITAL VELOCITIES

The release of neutral vapors into the upper atmosphere from orbiting vehicles such as the Space Shuttle will occur at hypersonic velocities. We have employed kinetic theory in order to predict the collisional braking and heating of such vapors. The vapor flow is described using a three-dimensional Boltzmann equation. The solution of the equation predicts the elongation of any vapor cloud injected at orbital velocities. It also predicts the heating of the vapor to over 2400 K. This study has been presented in a paper by Bernhardt (1979).

### 1.3 ELECTRON CONTENT STUDIES

On September 20, 1979, we made electron content measurements of the ionospheric hole created by the Atlas-Centaur launch of HEAO-C. A number of VHF polarimeters belonging to Stanford University and Alcorn State University were used to record the Faraday rotation of signals from geostationary beacons. From these data, electron contents were derived. The polarimeters are normally used for continuous routine measurements from the ATS-1 and ATS-3 satellites.

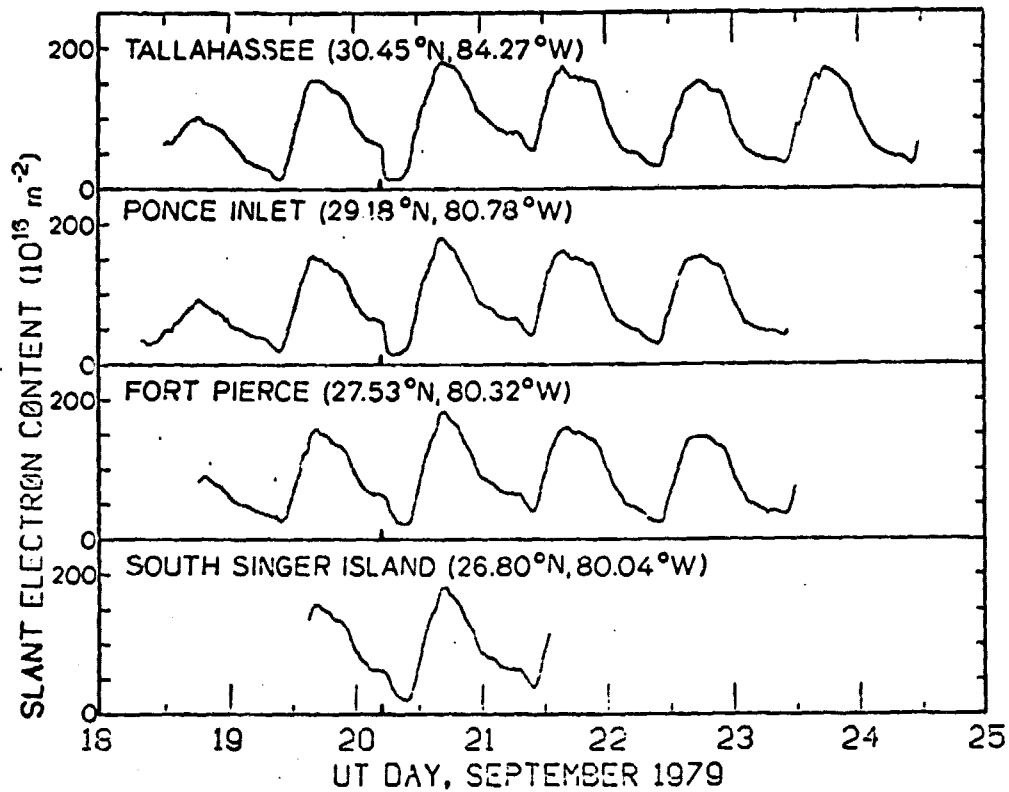


Figure 4: Electron Content Measurements

Ground receiving stations were set up at

Tallahassee	30.45° N,	84.27° W
Ponce Inlet	29.18° N,	80.78° W
Fort Pierce	27.53° N,	80.32° W
South Singer Island	26.80° N,	80.04° W.

Essentially continuous electron content measurements were made from the 18th through 24th of September, thus covering the time period before

and after the launch. The electron content variations at each station, as shown in Figure 4, are similar except for the period following 0528 UT on September 20, 1979, when the Centaur stage was firing into the F-region. The plot of the slant electron content versus time and versus latitude displayed in Figure 5 depicts the ionospheric hole formation. It can be seen that at the higher latitudes, where the rocket actually transversed the ionosphere, the hole was formed rapidly. The geographic extent of the effects of the exhaust vapors increases as time goes on owing to the expansion of the vapor cloud to lower latitudes.

The measurements described above constitute a new source of data for testing our ionospheric modification models. A paper analysing the results in further detail is being prepared in conjunction with other scientists who operated their own observation sites during the launch. We have continued our studies of the natural fluctuations in the electron content of the ionosphere. A paper reviewing the techniques for filtering electron content data is currently in press (Bernhardt, 1979). We also participated in a global study of the magnetic storm of June 17th and 18th, 1972 (Essex et al., 1980).

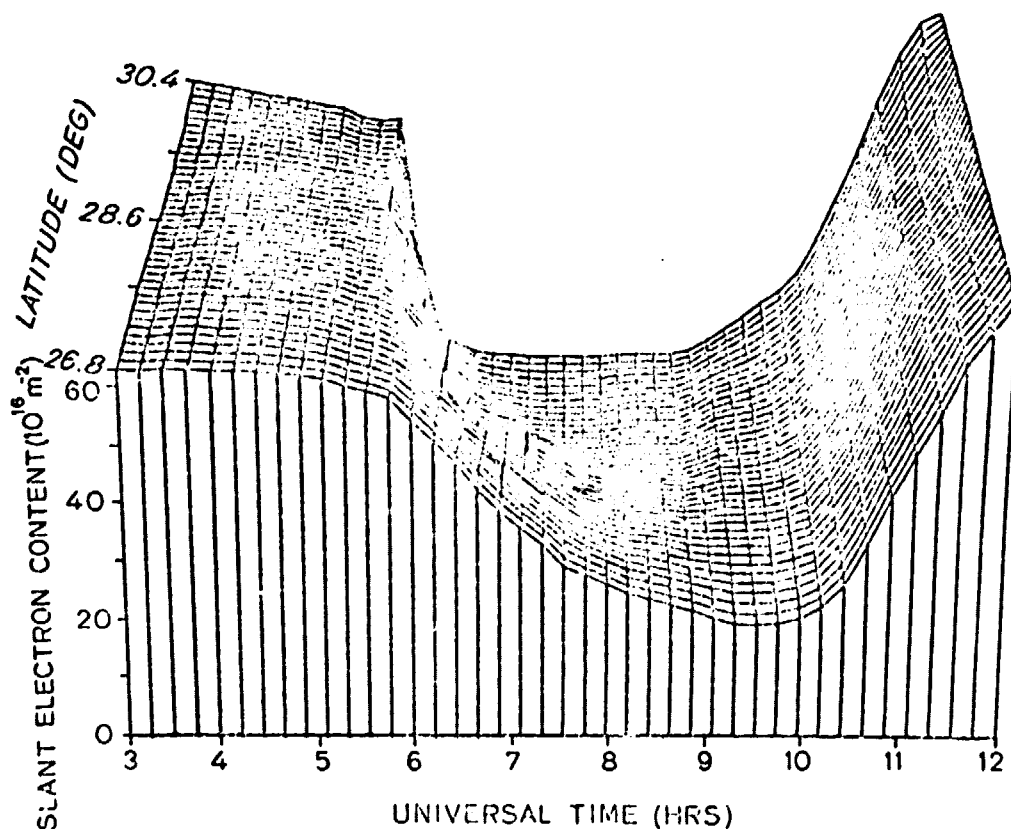


Figure 5: Electron Content vs Time and Latitude

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#### 1.4 CRITICAL FREQUENCY TRACKER

During the present reporting period, we have given considerable thought to the preliminary design of an inexpensive instrument capable of displaying, in real time and with excellent time resolution, the value of the electron concentration at the peak of the F2 region as well as the real height of the peak. We call this instrument the Critical Frequency Tracker or CFT for short. The result of our work is described in our proposal RL 2-80, for next years work, which is attached. We are now in a position to build the prototype of the Critical Frequency Tracker.

## Chapter 2

### FUTURE WORK

#### 2.1 CFT DEVELOPMENT

A proof-of-concept model of the Critical Frequency Tracker (CFT) will be built and tested as described in the attached proposal for next year's work. This is one main thrust of our effort for next year.

#### 2.2 CHEMICAL REACTION STUDIES

Additionally, theoretical work will be carried out on the study of dominant chemical reactions in the extra-terrestrial planetary vapor releases in the Earth's upper atmosphere. This work is described below.

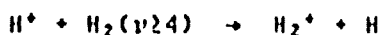
The atmospheric composition of the planets varies widely. While earth has nitrogen/oxygen atmosphere, our neighbors Mars and Venus has atmospheres dominated by carbon dioxide. The outer planets, Jupiter, Saturn, Uranus and Neptune have atmospheres dominated by hydrogen and hydrogen-rich molecules such as ammonia and methane.

The chemical processes that take place in the extraterrestrial atmospheres are not yet well understood. The chemistry can be studied in the laboratory provided conditions of temperature, composition, etc. of the atmospheres can be duplicated and provided also that one knows what chemical reactions to investigate. It is possible to complement laboratory work with studies of chemical injections into our own upper atmosphere, where some of the laboratory limitations can be overcome.

Reaction studies in the earth's atmosphere can take place under conditions closely matching those of alien atmospheres. Consider, for instance, this reaction



that has been suggested (Atreya et al., 1979) as an important mechanism for the removal of protons from the Jovian atmosphere. At room temperature (300 K), this exothermic reaction does not proceed at a measurable rate. In Jupiter's atmosphere where the temperature is thought to be 1300° K, the H<sub>2</sub> molecules may become vibrationally excited. The reaction



is exothermic and may occur with a rate as high as  $4 \times 10^{-9}$  cm<sup>3</sup>/sec.

The release of H<sub>2</sub> into the earth's atmosphere at 800 km altitude would permit the study of this reaction. The earth's exospheric temperature is 1200° K or greater. Thus, H<sub>2</sub> injections into the lower protonosphere could provide direct simulation of a portion of the Jovian chemistry.

There are numerous reactions of interest in planetary ionospheres which could be studied using gas releases into the earth's plasmasphere. A very brief sample is given in Table 1 (see footnote<sup>1</sup>).

<u>Reaction</u>	<u>Planet<sup>1</sup></u>	<u>Vapor Released</u>	<u>Terrestrial Ion</u>
$H^+ + H_2(v \geq 4) \rightarrow H_2^+ + H$	J, S	H <sub>2</sub>	H <sup>+</sup>
$H^+ + CH_4 \rightarrow CH_5^+ + H$	J, S	CH <sub>4</sub>	H <sup>+</sup>
$\quad \quad \quad \rightarrow CH_3^+ + H$	N, U		
$CH_4^+ + CH_4 \rightarrow CH_5^+ + CH_3$	J, S	CH <sub>4</sub>	H <sup>+</sup> or O <sup>+</sup>
$CH_5^+ \rightarrow CH_4 + H$	J, S	CH <sub>4</sub>	H <sup>+</sup> or O <sup>+</sup>
$CH_5^+ + NH_3 \rightarrow NH_4^+ + CH_4$	J, S	CH <sub>4</sub> , NH <sub>3</sub>	H <sup>+</sup>
$NH_4^+ \rightarrow NH_3 + H$	J, S	CH <sub>4</sub> , NH <sub>3</sub>	H <sup>+</sup> or O <sup>+</sup>
$H^+ + CO_2 \rightarrow COH^+ + O$	V, M	CO <sub>2</sub>	H <sup>+</sup>
$O^+ + CO_2 \rightarrow O_2 + CO$	V, M	CO <sub>2</sub>	O <sup>+</sup>

These reactions are from Chen, 1977, Capone et al., 1979, and Waite et al., 1979. The rates for most of the reactions for the outer planets are based on estimates.

In the next year, a survey will be made of reactions thought to take place in planetary ionospheres. We will estimate how these reactions can be studied by selective vapor releases into the earth's ionosphere and protonosphere.

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<sup>1</sup>The letters V, M, J, S, N, U refer to the planets Venus, Mars, Jupiter, Saturn, Neptune and Uranus respectively.

## PUBLICATIONS

Publications by our group during the past year are listed below.

Bernhardt, P. A., 'High Altitude Gas Releases: Transition from Collisionless Flow to Diffusive Flow in a Non-Uniform Atmosphere', JGR 84, 4341, (1979).

Bernhardt, P. A., 'Digital Processing of Ionospheric Electron Content Data', IEEE ASSP Transactions, December, (1979).

Essex, E. A., Mendillo, M., Schodel, J. P., Klobuchan, J. A., DaRosa, A. V., Yeh, K. C., Fritz, R. B., and Hibberd, F. H., 'A Global Response to the Total Electron Content of the Ionosphere to the Magnetic Storm of 17 and 18 June, 1972', J. Geophys. Res., submitted (1980).

Johnson, V., Sjolander, G. W., Oran, E. S., Young, T. R., Bernhardt, P. A., and DaRosa, A. V., 'F-Region above Kauai: Measurement, Model, Modification', J. G. R., to be published (1980).



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